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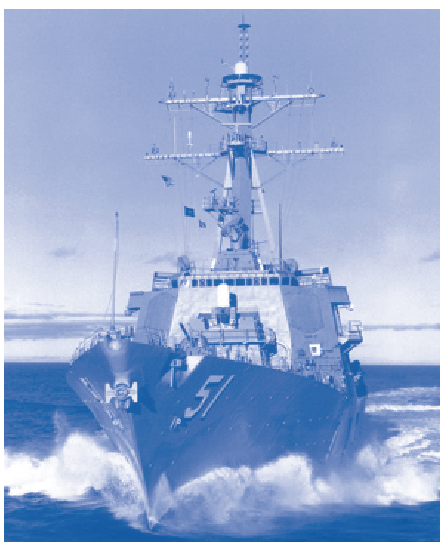
QUARTERLY 2007 No. 2



Gas Turbine Hot Section Corrosion Protection

A recently completed U.S. Navy ManTech program to investigate corrosion resistant Thermal Barrier Coatings (TBC) and identify alternative manufacturing methods for applying corrosion resistant coatings with improved microstructure and performance has been successfully concluded at iMAST.

Marine gas turbine engines serve as the primary and/or auxiliary power source for several classes of ships in the U.S. Navy fleet. It is a desired cost-driven goal that marine gas turbine engines have a mean time between removal (MTBR) of 20,000 hours, with ability to refurbish deteriorated hardware for additional service life without replacement. While some engines have approached this goal, others have fallen significantly short. In particular, the 501K-34 gas turbine has a current model specification overhaul cycle requirement of 16,500 hours. Time between overhaul (TBO) for this gas turbine engine has been falling significantly short (<10,000 hrs) of the goal/requirement primarily because of hot corrosion damage noted on high pressure turbine (HPT) hardware. (The primary mission of operation for the 501K-34 gas turbine falls directly in-line with the type II hot corrosion band.) This damage typically results from a combination of intrusive salts from inlet air supply to the engine, combined with sulfur found in gas turbine combustion fuels.

Type II hot corrosion (low-temperature corrosion) generally occurs over the temperature range of 600-750oC. Normally, chromia- or alumina-forming nickel-base alloys form a thin protective oxide (Cr_2O_3 or Al_2O_3) when exposed to oxidizing environments at elevated temperatures in air. In conditions where Type II corrosion occurs, transition metals, such as nickel and cobalt from the uncoated base alloy, react with SO_3 or SO_2 to form stable sulfates. These sulfates can react with the alloy oxides through acidic fluxing to alloy sulfides. Ni-Cr-Al-based metallic coatings have shown excellent resistance to Type II corrosion. In contrast, Type I hot corrosion (in the temperature range of 850oC to 950oC) starts when molten sulfate deposits, such as Na_2SO_4, deposit on the protective oxide scale surface. The sulfates react with alloy oxides via basic fluxing to form metal sulfides when thermodynamically and kinetically favorable. In addition, nickel and cobalt sulfides can result in catastrophic degradation of components as the molten sulfides dissolve the protective oxide layer and prevent the oxide from forming, and exposes the underlying superalloy. The Pt+Hf modified g'-Ni3Al+g-Ni-based coatings and MCrAlX (>25%Cr and 6%Al) materials have shown the greatest resistance to Type I and Type II hot corrosion in recent burner rig testing at Naval Surface Warfare Center Carderock (NSWCC).

Focus On Laser Processing

Continued on Page 7

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IN THIS QUARTERLY

DIRECTOR'S CORNER

Summer Is Here

It's hard to believe, but summer is here already! Spring was extremely busy for iMAST. Between new FY07 starts, and continuing projects from FY06, we have worked hard to manage over 40 ManTech projects. All of them are hard core contributions to support either existing challenges in the fleets, or our contribution towards affordable shipbuilding.

This quarterly newsletter issue includes an encapsulation of two projects we concluded this year: Hot Section Corrosion of Turbine Blades (S1017) and Collarless Construction (S1001). I think you will find them both quite interesting. The Hot Section project is aimed at fixing a long-standing problem with steam turbines. Resolving this high maintenance, availability and performance-limiting challenge has the promise of a near term Navy-wide impact. Collarless Construction is an affordability enhancement project that may have significant impact on how hulls are constructed by the shipbuilders that support the U.S. Navy and Coast Guard.

We use this newsletter, in part, to inform our customers, sponsors and stakeholders of what we're doing to support the Navy, Marine Corps and DoD in general. If you have feedback on our articles, or would like more information on our work, please do not hesitate to contact us. We are committed to our mission of supporting the men and women of our Armed Forces with leading-edge technology, as well as applications that enhance existing technology. If you would like to contact us, please feel free to contact me directly at <tdb14@ psu.edu>, or call 814-863-3880. Also take a look at our website which is <www. arl.psu.edu/capabilities//mm_imast.html.

Thank you for taking time to hear about what we have been up to. Have a great summer!

Tim Bair

MATERIALS PROCESSING TECHNOLOGIES

MECHANICAL DRIVE TRANSMISSION TECHNOLOGIES

LASER PROCESSING TECHNOLOGIES

COMPLEX SYSTEMS MONITORING TECHNOLOGIES

ADVANCED COMPOSITES MATERIALS TECHNOLOGIES

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Focus on Laser Processing

Development of Collarless Construction Techniques for Surface Combatants

by Richard P. Martukanitz, Ph.D.

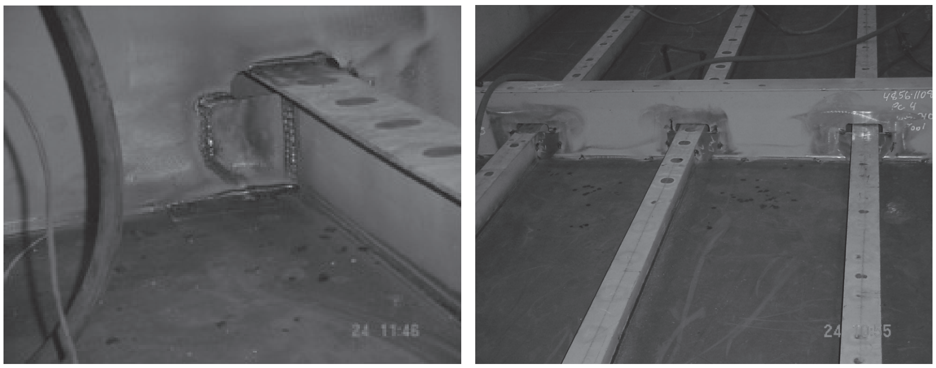

Figure 1. Photographs showing collar details and structure for a typical arrangement used for ship construction.

A program was recently completed to determine the feasibility of improving the affordability of collar construction during Navy ship fabrication. The program, led by the Institute for Manufacturing and Sustainment Technologies (IMAST) and originally funded by the Surface Strike Affordability Initiative, was tasked with identifying potential designs that would reduce the labor associated with collar installation, test viable designs to verify structural performance, and develop tools for use in implementing the technology for construction of the next generation of surface combatants. The program team consisted of General Dynamics Bath Iron Works (BIW), Northrop Grumman Ship Systems (NGSS), the Naval Sea Systems Command (NAVSEA), the Naval Surface Warfare Center Carderock Division (NSWCCD), the Navy Joining Center (NJC) of the Edison Welding Institute, Advanced Computation and Engineering Services (ACES), and the Applied Research Laboratory, Pennsylvania State University (ARL Penn State).

USE OF COLLARS

Navy shipbuilders reinforce bulkhead and deck plates with a grid of longitudinal and transverse stiffeners welded to those plates to resist various pressures, e.g. flooding, weapons, and wave-induced effects. The rib-like transverse frames extend from the keel outward around the turn of the bilge and up the sides, helping define the ship's form. Longitudinal stiffeners run parallel to the keel along the bottom, bilge, and side plates, as well as along internal decks and longitudinal bulkheads. Since the stiffeners cannot be fully cut out at intersections and still maintain the strength of the plate assembly, the deeper member (usually the transverse frame) is notched to fit over the longitudinal stiffener, allowing the bottom edges of both to be flush with the deck for welding purposes. Simultaneously, that notch causes a gap of several inches between the web face of each beam and the clearance cut. To maintain the structural integrity and strength of the assembly, as well as to prevent water and other materials from entering these gaps when a tight fit is required, welders join collars or clips at the notched intersections of these stiffeners.
A typical collar arrangement for penetrating a transverse member for construction of a combatant is shown in Figure 1.

ALTERNATE TECHNIQUES

Various alternate collar configurations were evaluated under the program. These evaluations included significant application of structural analysis using numerical techniques (non-linear finite element analyses), large-scale testing under various loading conditions, and shipyard

PROFILE

Rich Martukanitz is a senior research associate and head of the laser processing division in ARL Penn State's Materials and Manufacturing Office. Dr. Martukanitz holds B.S. and M.S. degrees in metallurgical engineering from The Pennsylvania State University and University of Pittsburgh (respectively). He received his Ph.D. degree in materials science and engineering from The Pennsylvania State University.

Dr. Martukanitz serves on the board of director of the Laser Institute of America and has been previously listed in Marquis' Who's Who in Science and Engineering. His research interests include the development of quantitative relationships governing the stability and kinetics of material reactions occurring during rapid thermal processing with lasers, as well as development and application of laser processing technology.

Prior to joining ARL Penn State, Dr. Martukanitz was employed by the Alcoa Technical Center in Pittsburgh, PA. Dr. Martukanitz can be reached at (814) 863-7282. or by e-mail at <rxm44@psu.edu>.

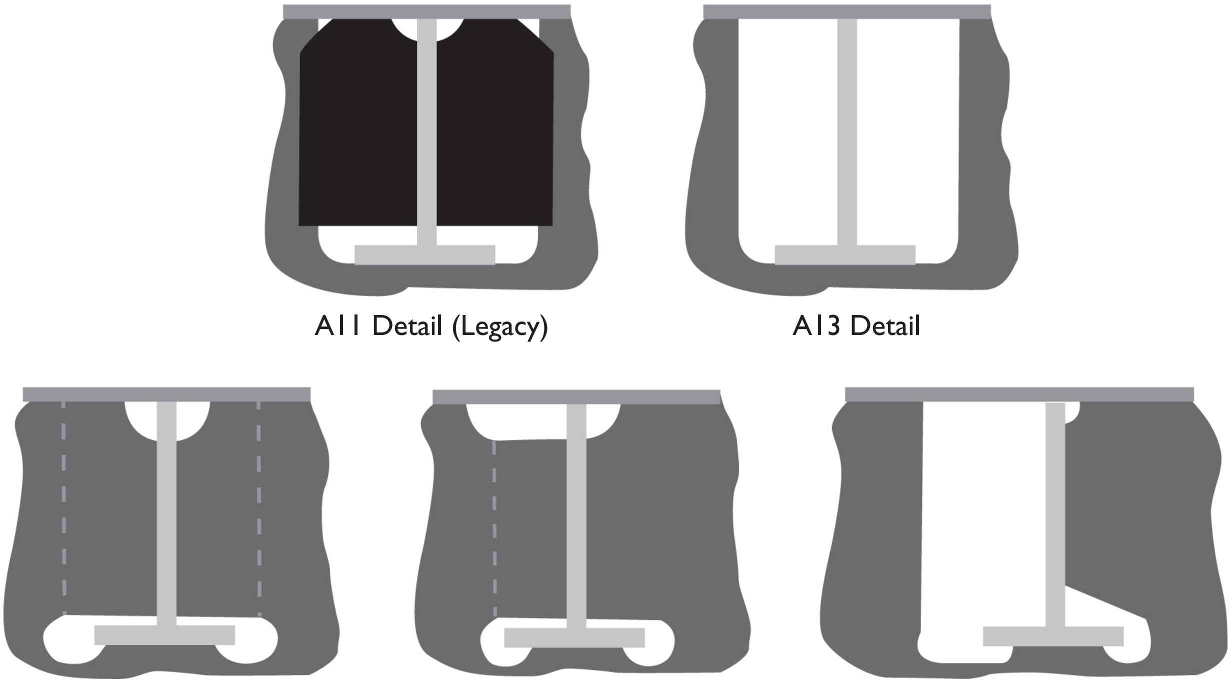

Figure 2. Legacy design and alternate collar concepts evaluated under the program to improve affordability of collar construction.

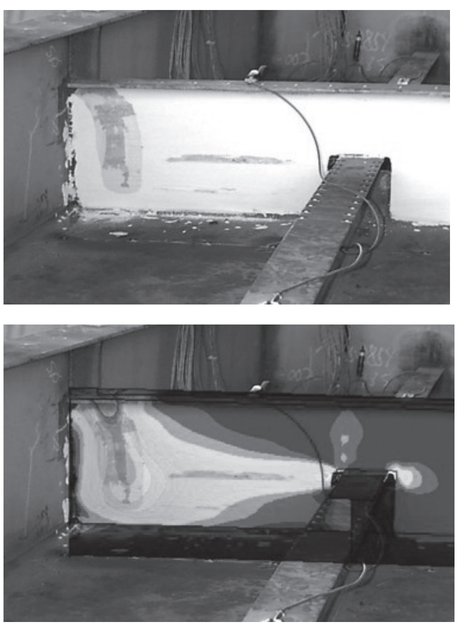

Figure 3. Photographs of the tranverse member and collar of a panel during hydrostatic testing at Northrop Grumman Ship Systems showing brittle coating (top) and superimposed results of finite element analysis (bottom).

producibility studies to gage the potential for reducing cost. In all cases, the alternate collar configurations were directly compared to the collar design currently used for U.S. Navy ship construction.

The alternate collar concepts that were evaluated are shown schematically in Figure 2 and can be placed into two broader categories, collars that enable longitudinal stiffeners to be placed directly into the penetration and joined, such as the A13 and E2 concepts, or collars that require bending of tabs for positioning of stiffeners and joining, such as the DR11 and H2 designs. Obviously, these techniques are dependent upon the current fabrication styles used within a shipyard, and hence, the two shipyard partners in this program expressed interest in an individual category, based on the ability to implement the technique in their respective manufacturing environment. The bendable tab concept is believed to provide greater utility for fabrication of large structures, while direct insertion into penetration, that is provided with the A13 design, would be more viable for subassembly fabrication. However, implementation of these techniques would have to satisfy the structural performance characteristics of the current or legacy collar design.

Detailed plans and protocol were developed to structurally test the alternate configurations under various loading conditions. These tests were formulated under the auspices of the Naval Sea Systems Command and included: hydrostatic pressure tests designed to indicate the influence of collar location on response under hydrostatic loads, longitudinal compression tests to assess the effect of collar designs on the buckling response of the longitudinal members, cyclic loading to assess the potential for long-term fatigue failure, and dynamic tests to measure the ability of viable designs to survive a weapons effects. All tests were conducted on large-scale structures that were fabricated using standard shipyard

practices, were supplemented by rigorous numerical simulations, and involved direct comparisons to the standard Navy collar design. Figures 3 and 4 depict photographs obtained during hydrostatic testing and longitudinal compression testing of the various collar configurations, respectively.

RESULTS OF EVALUATIONS

Results of shipyard producibility trials indicated that, within the current Navy shipbuilding environment, the truly collarless design of A13, as well as the DR11 or H2 designs that utilize bendable tabs, offer the potential for improved affordability for collar installation. The use of these alternate collar configurations is anticipated to decrease time required for collar installation by 20%. Given the large numbers of collars that may be present within a surface combatant, this improvement may result in significant cost savings. However, economic considerations must also be weighed against structural requirements within a particular ship structure. Figure 5 shows photographs of the DR11 design being employed for construction of the hydrostatic tests panels at Northrop Grumman Ship Systems.

The results of extensive structural analyses of the various alternate collar configurations have indicated that designs offering greater compensation of the transverse member, such as the DR11 and H2, provide greater ability to carry shear and bending loads within the transverse structure; whereas, pure collarless configurations that provide less compensation, such as the A13 or E2 designs, may be appropriate in areas subject to lower stress conditions. Designs that result in less compensation of the transverse member require detailed analyses of the stresses present within the structure for location specific utilization. Because of the potential savings associated with the pure collarless design, a methodology supported by engineering data has been compiled to enable naval architects and engineers to determine the applicability of these designs based on projected stresses present within a specific structure.

In the context considered under this effort, compensated configurations that encompass the bendable tab designs have been shown to be a viable alternative for direct replacement of the baseline A11 configuration. Although promising, the results of structural tests for these designs are currently being reviewed by the Naval Sea Systems Command and have not yet been approved for direct substitution. Should these designs be approved for direct substitution for U.S. Navy platforms, the potential savings afforded by these techniques should also provide incentive for shipyard development of optimized tooling to easily form the bent tabs.

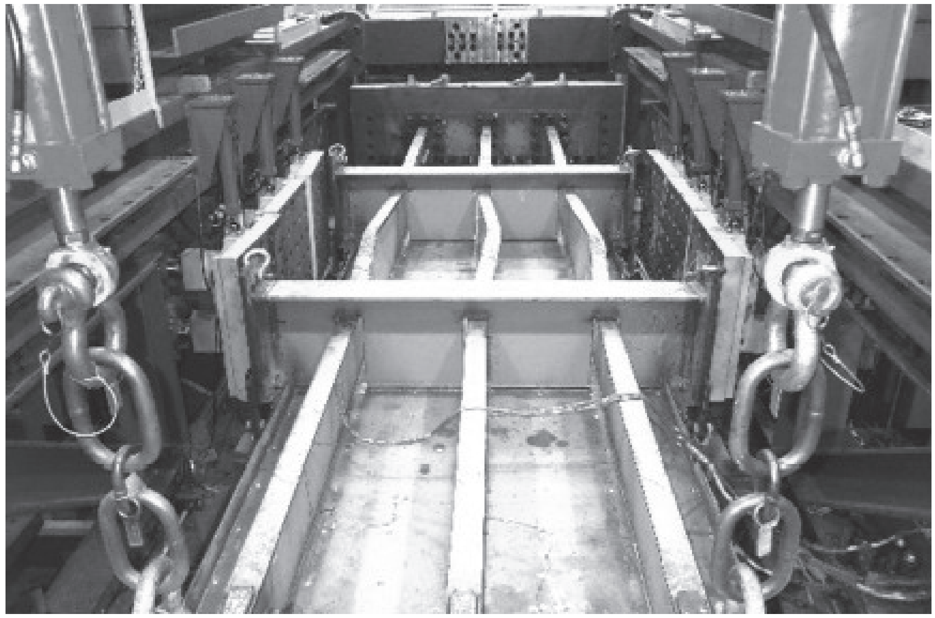

Figure 4. Photograph of panel being tested under longitudinal compression at the Naval Surface Warfare Center Carderock Division.

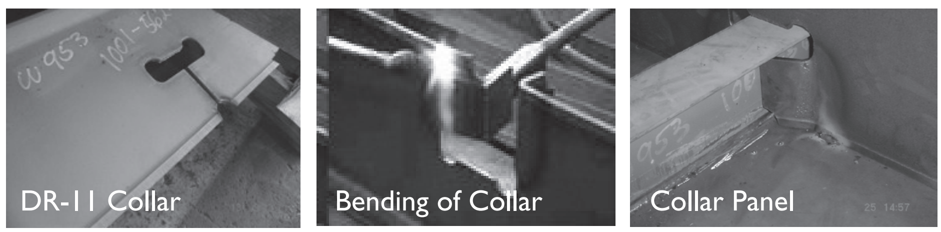

Figure 5. Photographs showing a bendable tab design being employed for construction of the hydrostatic tests panels at Northrop Grumman Ship Systems.

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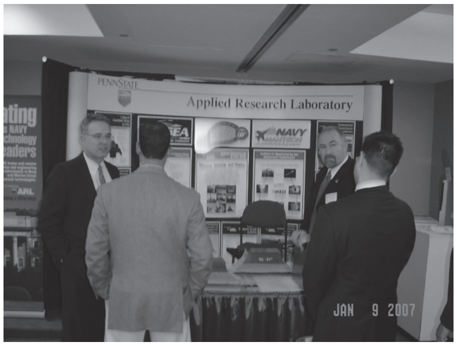
The author wishes to express appreciation for support of this effort by ARL Penn State's Institute for Manufacturing and Sustainment Technologies (iMAST), a U.S. Navy ManTech Center of Excellence sponsored under contract by the Navy Manufacturing Technology Program, Office of Naval Research. Any opinions, findings, conclusions and recommendations expressed in this material are those of the author and do not necessarily reflect the views of the U.S. Navy.



Surface Navy Association Symposium

iMAST participated in the annual Surface Navy Association symposium held in Crystal City, Virginia. Featuring Navy ManTech program efforts and specific project artifacts, iMAST provided information dealing with programs that support innovative naval surface platform technologies, as well as materials and manufacturing techniques applied in naval construction. Numerous flag officers, industry representatives, and Navy program managers visited the iMAST exhibit booth. Symposium guest speakers included the Secretary of the Navy, as well as Dr. Delores Etters, Assistant Secretary of the Navy for Research, Development and Acquisition.

ICAF Manufacturing Industry Study Group

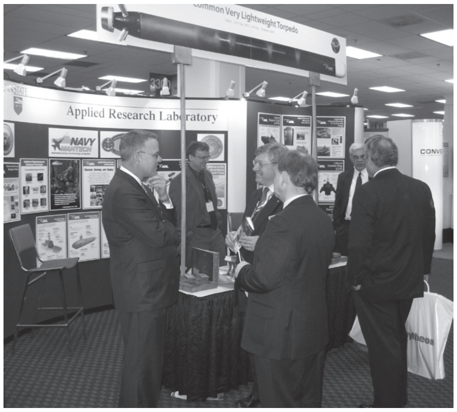
The director of iMAST briefed members of the Industrial College of the Armed Forces (ICAF) Manufacturing Industry Study Group (MISG) on the U.S. Navy Manufacturing Technology program, as well as iMAST's Center of Excellence at Penn State. The briefing provided an opportunity to acquaint future DoD industrial base leaders with the ManTech program as both a reference base and resource. The group of 18 joint service O-5/O-6 and civilian-equivalent students and faculty are currently attending/instructing ICAF (a joint service War College/senior service-level school). The students are concentrating their studies on the manufacturing industry that supports the DoD. ICAF's cirriculum includes several domestic industry visits and two weeks of travel to Germany and Russia. The National Center for Defense Metals Manufacturing hosted the event in Latrobe, PA. The briefing was designed to orient the students to the role of ARL and ManTech in supporting the Navy and Marine Corps. It also provided a forum to discuss current trends in manufacturing, as seen from the perspective of a Navy ManTech COE.

CVN-21 ManTech Program Review

iMAST director, Tim Bair, attended and particpated in the CVN ManTech program review hosted by Northrop Grumman at Newport News, VA. The conference was attended by members of the ManTech team and representatives of several of the COE's including iMAST, EMPF, CNST, NMC, EWI, NSWCC, CVN 21 program office, and NGNN. Several projects were reviewed. iMAST's Improved Advanced Watertight Door was briefed by Dr. Stephen Copley. The watertight door results show promise and appear to support efforts to get OCI waiver approval to subcontract with NGNN on door installation testing.

End of Project Demonstration

iMAST hosted a demonstration of the hybrid laser-arc pipe welding system currently being developed under a U.S. Navy ManTech project sponsored by the Center for Naval Shipbuilding Technology (CNST). Numerous pipe schedules were successfully hybrid-welded for representatives from Northrop Grumman Ship Systems, Northrop Grumman Newport News, Electric Boat, Edison Welding Institute, PLSystems, Trumpf, Inc., Sunset Metal Works, Wolf Robotics, and Servo Robot. The welding system has been shipped to National Steel & Shipbuilding Company (NASSCO) for implementation. iMAST has worked closely with CNST to help make this project a success.



Navy League Sea-Air-Space Expo

Members of iMAST attended and participated in the annual Navy League Sea-Air-Space Expo held in Washington D.C.. This annual event draws numerous visitors to include senior DoD, Navy, Marine Corps, and Coast Guard officials, as well as senior industry representatives. This year's theme "Sea Power to Secure Victory" drew a large crowd and many notable visitors. iMAST provided individual Navy ManTech project overviews and displayed project-related items that caught the attention of various senior military leaders. Notable visitors to the exhibit booth included the Vice Chairman of the JCS (Admiral Giambastiani), CNO (Admiral Mullen), Assistant Secretary of the Navy for Research, Development & Acquisition (Dr. Etters), as well as the Director of Naval Nuclear Propulsion (Admiral Donald), and the Assistant Commandant of the Marine Corps (General Magnus). The annual Navy League Sea-Air-Space Expo provides an excellent opportunity for iMAST to showcase its capabilities.

CONTINUED FROM COVER

501K-34 HPT engine hardware, including turbine blades, vanes and 1st stage bladetracks, have shown limited life due to Type II hot corrosion. Current PtAl coated 1st stage blades are showing corrosion related distress at approximately 6,000 hours of engine run time which is becoming a serious overhaul concern. In addition, corrosion attack under the shroud area of 3rd stage turbine blades (resulting from corrosion attack/coating porosity issues) continues to hinder this engine from meeting overhaul goals. An urgent need exists to develop a cost effective 20,000 hr (non-line of sight dependent) life coating and application process.

A Navy ManTech program was initiated during 2004 to investigate corrosion resistant Thermal Barrier Coatings (TBCs) and alternative manufacturing methods for applying corrosion resistant coatings with improved microstructure and performance. The main deposition methods for applying the nickel-aluminides or Pt-modified aluminide bond coatings are plating, chemical vapor deposition (CVD), pack cementation, whereas MCrAlX coatings are generally applied by low-pressure plasma spray (LPPS) and electron beam-physical vapor deposition (EB-PVD). However, metallic EB-PVD coatings are being phased out due to cost/performace issues, and alternative manufacturing methods are needed. In addition, it was desirable to reduce the manufacturing cost and improve coating quality while applying corrosion resistant metallic CoCrAlX coatings.

Joint discussion and collaboration efforts with NAVSEA, NAVAIR, Foreign Comparative Test (FCT) program, and the Navy ManTech engine program, provided iMAST an opportunity to assist in identifying alternative metallic coatings, materials and coating deposition processes for improved performance against hot corrosion. In an effort to maximize resource dollars, the NAVY ManTech Program collaborated with the (FCT) program to test and evaluate the best coating systems for different engine base alloys, temperature ranges, and coating classifications. Various pre-screening selections were made on MCrAlX composition applied by various coating techniques to replace the current argon shielded and electron beam physical vapor deposition technique of metallic alloys that is being phased out. The ManTech/FCT burner rig tests showed Pratt and Whitney's “Coating A”, applied by cathodic arc performing extremely well, and was identified as a go forward coating for 501K-34 2nd stage vane and blade hardware at engine overhaul. In addition, Iowa State University's (ISU) Pt+Hf modified g'-Ni3Al+g-Ni-based coating compositions also showed “outstanding” protection against hot corrosion and is an area for future follow on efforts.

Based on numerous internal reports, data, testing and analysis, combined with favorable coating microstructures, thickness profiles, and burner rig test results conducted by Pratt and Whitney at their cost, Pratt and Whitney's "Coating A" was transitioned to stage II blades and vanes for the 501-K34 engine as a repair technology solution during Spring of 2007.

For more information on this effort, please contact Doug Wolfe, Ph.D. at (814) 865-0316, or by e-mail at <dew125@psu.edu>.

CALENDAR OF EVENTS

2007

9–11 Jan.	Surface Navy Association Symposium	★★★★★★★ *visit the iMAST booth*	Crystal City, VA
30–31 Jan.	ShipTech 2007	★★★★★★★ *visit the iMAST booth*	Biloxi, MS
3–5 April	Navy League Sea-Air-Space Expo	★★★★★★★ *visit the iMAST booth*	Washington, D.C.
6–19 April	Aging Aircraft Conference		Palm Springs, CA
10–12 April	SME Composites Manufacturing		Salt Lake City, UT
1–3 May	American Helicopter Society Forum 63	★★★★★★★ *visit the iMAST booth*	Virginia Beach, VA
7–9 May	Navy (SBIR) Opportunity Forum		Crystal City, VA
30 – 31 May	Letterkenny Depot Business Showcase	★★★★★★★ *visit the iMAST booth*	Chambersburg, PA
31 May – 1 June	Johnstown Showcase for Commerce	★★★★★★★ *visit the iMAST booth*	Johnstown, PA
30 July – 2 Aug	ONR Naval Industry Partnership Conference	★★★★★★★ *visit the iMAST booth*	Washington, D.C.
15–17 Aug	Armstrong County Showcase for Commerce	★★★★★★★ *visit the iMAST booth*	Kittanning, PA
20–24 Aug	Penn State Rotary Wing Technology Short Course		University Park, PA
23–25 Oct	Expeditionary Warfare Conference		Panama City, FL
2–4 Oct	Marine Corps League Modern Day Marine Expo	★★★★★★★ *visit the iMAST booth*	Quantico, VA
7–10 Oct	AGMA Gear Expo		Detroit, MI
9–11 Oct	AUSA Expo		Washington, D.C.
29 Oct – 1 Nov	U.S. Coast Guard Innovation Conference		New Orleans, LA
12–15 Nov	Logistics Officer Association Conference		Washington, D.C.
13–16 Nov	DoD Maintenance Conference	★★★★★★★ *visit the iMAST booth*	Orlando, FL
3–6 Dec	Defense Manufacturing Conference	★★★★★★★ *visit the iMAST booth*	Las Vegas, NV

Quotable

"Everything should be made as simple as possible — but not simpler."
— Albert Einstein

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